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To: Dr. D. Mills
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SF_6 AND THE ATMOSPHERE

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SUMMARY

Ontario Hydro operates eight gas-insulated substations and many puffer-type circuit breakers which contain compressed SF_6 gas for insulation and arc interruption purposes. The occasional release of SF_6 into the atmosphere, either through small leakage from the switchgear equipment or discharge during equipment repair, has raised concerns about the possible environmental effects. In urban areas where existing or future stations are located, such release may be governed by regulations regarding disposal of substances which contribute to the greenhouse effect or ozone destruction in the atmosphere.

Recognizing the concerns that there is a lack of information on whether SF_6 contributes to the greenhouse effect and ozone destruction, staff at the Research Division and ABB Corporate Research have conducted a preliminary investigation. The results of the study show that SF_6 absorbs strongly in the middle infrared region (10 μm). SF_6 therefore has roughly the same greenhouse efficiency as the CFCs (chlorinated fluorocarbons) which absorb infrared in the same wavelength region. Based on world-wide SF_6 production rates and release data, the abundance of SF_6 in the atmosphere is estimated to be 0.0015 ppb (parts per billion) which is about 1000 times less abundant than the CFCs. The overall contribution of SF_6 to the greenhouse effect is less than 0.01%. In comparison, the relative contributions of CO_2 and CFCs are respectively 60% and 12%. The investigation also determines that SF_6's contribution to stratospheric ozone destruction is negligible.

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The study is summarized in a paper to be submitted to the IEEE Transaction on Electrical Insulation for publication (Appendix A). The paper points out that the environmental effects of SF_6 can further be minimized by recycling the used gas. This practice has long been adopted by Ontario Hydro for safety and economic reasons. Information contained in this report will be useful to substation maintenance personnel in establishing improved gas handling guidelines and in addressing any environmental concerns.

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SF_6 AND THE ATMOSPHERE

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Abstract - The possible environmental effects of SF_6 released into the atmosphere are assessed. It is shown that the relative contribution of SF_6 to the greenhouse effect is less than 0,01 %. SF_6's contribution to stratospheric ozone destruction is negligible.

1. Introduction

SF_6 used in heavy electrical equipment, such as gas insulated switchgear and substations, accounts for about 80 % of the world's production which is estimated to be between 5000 and 8000 t / year in 1990. The occasional release of SF_6 into the atmosphere, either through small leakage from equipment or discharge during equipment repair or maintenance, has raised concerns about the possible environmental effects. Using available data, the relative contribution of SF_6 to atmosphere pollution has been assessed with emphasis on the greenhouse effect and stratospheric ozone destruction. The implications for the electrical industry and the adequacy of current SF_6 handling procedures are discussed.

The quantitative contribution of SF_6 to atmospheric pollution is best analyzed in relation to the effects caused by CFCs (chlorinated fluorocarbons*)) as the latter have been thoroughly studied in the last decade

*) For simplicity, we will include in these also the fully fluorinated (chlorine free) species such as CF_4 and C_2F_6

and are suspected to contribute to such atmospheric pollution phenomena as the greenhouse effect and stratospheric ozone depletion [1] [2]. The data required to approximately quantify the problem are as follow:

- the quantities of CFCs and SF_6 having been released into the atmosphere hitherto, the present annual production rates, and their growth trends for the future.

- the relative "greenhouse" efficiency of SF_6 in comparison to the one of the CFCs

- the relative stratospheric ozone destruction efficiency of SF_6 in comparison to the one of the CFCs.

2. Present and past concentrations and production rates of CFCs and SF_6

An estimate of the amount of CFCs and SF_6 released into the atmosphere can be obtained from 2 sources, namely, the past global annual production rates and the measured atmospheric trace concentrations.

According to [1] the world-wide annual production rate of CFCs has been increasing more than linearly since 1970 and is at present about

1 000 000 t / yr CFCs (1)

There is still no indication of change in the rising trend. The average atmospheric trace concentration of all CFCs together according to [2] is currently about

1,6 ppbv **) CFCs (2)

(Extrapolation of data measured in 1980 and 1985.)
The world-wide production rate of SF_6 according to [3] has approximately risen linearly from 1970 to a present estimated

7000 ... 8000 t / yr SF_6 (3)

and is expected to rise to about 10 000 t/a in the year 2010 (fig. 1a). From these data, the average atmospheric trace concentration can be calculated based on an equivalent height of the atmosphere of 8 km. Two limiting cases are shown in fig. 1b, namely full release of all produced SF_6 into the atmosphere (full curve) and leakage losses only (~1 % of production, broken curve). The point in fig. 1b represents the last atmospheric trace measurement carried out in 1980 [2] and is already below the full release curve. A trend estimate also given in [2] is represented by the broken curve which assumes the increasing containment and recycling. This curve predicts a present atmospheric trace concentration of SF_6 of about

0.0015 ppbv SF_6 (1990) (4)

from which we obtain the ratio

$$\frac{\text{atmospheric concentration of } SF_6}{\text{atmospheric concentration of CFCs}} < 10^{-3} \quad (5)$$

**) 1 ppbv is one part per billion in volume

i.e. SF_6 is by a factor of 1000 less abundant than the CFCs with a trend to a further substantial reduction of this ratio.

3. Greenhouse effect

The average temperature of the troposphere is stabilized by the fact that infrared radiation emitted from the earth's surface is partly reflected back by atmospheric gases with high infrared absorptivity (and thus reflectivity) such as H_2O and CO_2. The wavelength range of this reflection is critical is the "atmospheric window" 7 - 13 µm [2]. The natural reflectivity of the troposphere in this spectral range (as caused by CO_2, H_2O, and O_3) is increased by man-made gases such as CH_4 (cattle), CO_2 (fossil fuel burning), N_2O (fertilizers), and the CFCs. As a result, the average temperature at the earth's surface is expected to increase. This warming is popularly known as the greenhouse effect.

To quantify the contributions of the different man-made gases to global warming, each is assigned a greenhouse efficiency based upon its infrared absorption characteristics in the atmospheric window. By inserting these data into climatic model calculations, one finds that the CFCs have to date contributed more than 12 % to the total global warming (table 1) [4] and that there is a tendency for this share to increase in the future [2].

As can be seen from fig. 2, the absorption characteristics of SF_6 in the atmospheric window are similar to those of the CFCs [5]. SF_6, therefore, has roughly the same greenhouse efficiency as the CFCs. Therefore, based on the concentration ratio eq. (5), and the CFC con-

tribution to the total greenhouse effect according to table 1 we have to conclude that

SF_6 contributes to the greenhouse
effect with less than 10^{-4} or 0.01 % (6)

In the future this figure will further decrease by about two orders of magnitude as SF_6 will be increasingly recycled and only leakage losses (< 1 % per year) will determine the ultimate SF_6 release.

4. Stratospheric ozone destruction

The depletion of stratospheric ozone by CFCs originally hypothesized in 1975 is now an established fact [1]. The ozone destruction mechanism consists in the catalytic reactions

$$h\nu\ (UV) + CFC \rightarrow Cl + other$$

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + O \rightarrow Cl + O_2 \qquad (7)$$

$$O + O_3 \rightarrow 2\,O_2$$

i.e. ultraviolet (UV) radiation quanta hν photolyze a CFC molecule to produce atomic chlorine Cl, which in turn dissociates ozone O_3 and is recycled as a catalyst so that the sum reaction leads to ozone

destruction. Typically, one chlorine atom is recycled 10 000 times before it is neutralized by other reactions. Similarly efficient reaction schemes exist for bromine Br and iodine I. These halogenes, however, are less abundant. For fluorine F which is the only halogenic constituent of SF_6, the above catalytic reaction scheme is inefficient because of two facts:

(a) Due to the structure of its ultraviolet absorption spectrum SF_6 is not photolyzed in the critical "ozone destruction" altitude range between 32 and 44 km [2] so that no atomic fluorine is supplied by SF_6.

(b) Due to the high chemical affinity of fluorine F to hydrogen H, which is abundantly present in the stratosphere, any atomic F that may have been produced is rapidly neutralized by the formation of HF. This makes the ozone destruction efficiency of atomic fluorine, if available, by a factor 10 000 lower than the one of chlorine [6].

As a consequence of (a) and (b) there are two reasons to conclude that SF_6 does not contribute at all to stratospheric ozone destruction.

5. Ecology conscient SF_6 handling

Nonwithstanding its present low atmospheric concentration, SF_6 has a very long atmospheric life time (> 500 years according to [2]). Therefore a long-term accumulation in the atmosphere should be kept as low as possible. For this reason, utilities should be encouraged to systematically recycle SF_6 or have used SF_6 purified by the SF_6 manufacturers who are ready to do this. This policy would offer the following benefits:

(1) The release of SF_6 into the atmosphere would be reduced to the very low leakage losses which are below 1 % per year for present equipment.

(2) SF_6 recycling is technically feasible and economically attractive because of its relatively high cost.

(3) Systematic SF_6 recycling could become an example for an industrial recycling process introduced by its users voluntarily and not as a reaction to legislation.

To the authors' knowledge, an SF_6 recycling policy has already been adapted by many utilities as part of their SF_6 handling procedures for both safety and economic reasons. Implementation of sound SF_6 handling procedures therefore will further minimize possible environmental impact.

6. Acknowledgements

The authors would like to thank Dr. Frank Bartoszek of Ontario Hydro Research for supplying background information on the greenhouse effect.

7. References:

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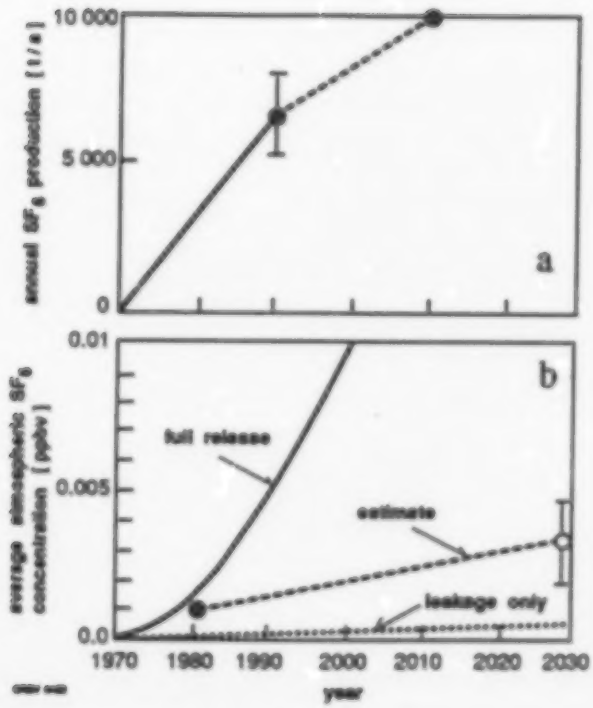

Fig. 1 Estimated annual SF_6 production (worldwide) and calculated average atmospheric trace concentration under the worst-case assumption of full release (full curve) and the best case assumption of leakage only (dotted curve). Actual estimate according to [2] (broken curve).

Fig. 1
Niemeyer, Chu

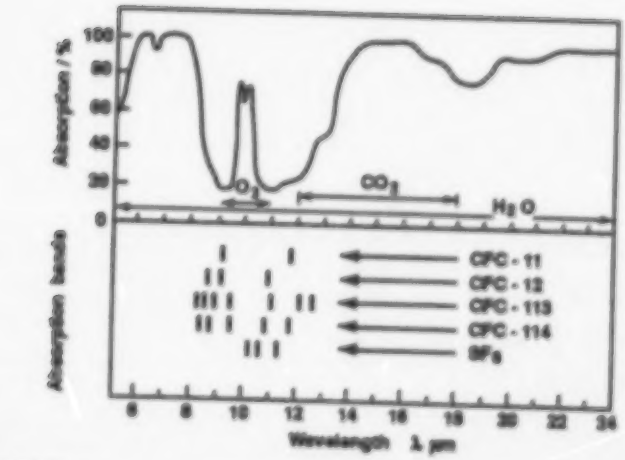

Figure 2 The infrared absorption spectrum of the atmosphere in the region in which the Earth emits. Absorption bands of CFCs and SF_6 in the "atmospheric window" (from ref. [5])

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Table 1 Estimated contribution of various gases to the greenhouse effect after [4].

Species	Concentration (ppbv)	Rate of increase (% per year)	Relative contribution (%)
CO_2	353×10^3	0.5	60
CH_4	1.7×10^3	1	15
N_2O	310	0.2	5
O_3	10-50	0.5	8
CFC-11	0.28	4	4
CFC-12	0.48	4	8
SF_6	0.002	5	$<10^{-2}$